KA-BAND RADAR MOMENT STATISTICS AND ASPECTS OF ACCURACY

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ABSTRACT

The Ka-band radar MIRA36 at Lindenberg is an indirectly calibrated system based on the estimates of the gain and loss of all components. The maximum uncertainty of this calibration method has been appraised to be 3.0 dBz. Statistics of radar Doppler moments provide not only information about target distribution and properties but also about the performance of the radar and their temporal stability. Time series of reflectivity show a minor long term drift of reflectivity over the 8 years period of radar operation. While at 500 m the reflectivity decreases by about 1 dBz, an increase of up to 2.6 dBz can be observed at upper heights. These changes can be caused by natural variations or by system drifts.

Key words: Ka-band radar, moment statistics.

1. INTRODUCTION

During the last decades millimeter-wave radars have been established as useful systems to detect hydrometeors and to derive macro- and microphysical cloud parameters [6, 5]. Since November 2003 the Meteorological Observatory Lindenberg (DWD) is operating continuously MIRA36, a 35.5 GHz coherent and polarimetric cloud radar to measure vertical profiles of reflectivity, Doppler velocity, spectral width and the Linear Depolarisation Ratio (LDR) (named as moments in the following) between 250 m and 15 km height [3, 4] with a vertical resolution of 30 m. Despite the good performance of the radar the accuracy of moments particularly of derived reflectivity is crucial especially for the estimation of microphysical cloud parameters. Therefore, a well calibrated and stable radar is a prerequisite for the application of many retrieval techniques and for providing cloud parameters comparable between different locations.

The radar reflectivity Z is proportional to the signal-to-noise ratio (SNR) of the received signal and to the square of range r, whereby the proportionality factor C takes into account all system properties

$$Z = C\, r^2\, SNR \tag{1}$$

The determination of C - usually denoted as radar calibration - is still a challenging task for radar operators. Especially for vertical pointing radars with a fixed antenna and narrow beam width (large apertures) a calibration against a reference target with a well defined radar cross section is difficult to realize. Therefore, the indirect method (named also as budget calibration) is still used for calibrating MIRA36. Despite taking utmust care during the budget calibration the sum of all uncertainties is bigger than user requirements. For this reason, additional independent methods to monitor the calibration factor of the radar are necessary for quality assurance.

If a direct calibration, e.g. against a reference target or by comparison against other well calibrated radars can not be realized statistics of moments may provide a first idea about system performance and stability. In the following an error estimation of reflectivity for MIRAs budget calibration and some statistics of moments are presented.

2. THE KA-BAND RADAR MIRA36 AND ERROR ESTIMATION OF REFLECTIVITY

The radar MIRA36 is designed for long term measurements and is equipped with a magnetron transmitter to provide radio frequency (RF) pulses with a maximum power of 30 kW. The radar has a vertically pointed Cassegrain antenna with a polarization filter, two receivers for simultaneously receiving co- and cross-polarized signals and a computer including a DSP board for data acquisition and processing. In February 2010 the radar was equipped with a higher gain antenna and a digital receiver which led to an increase of sensitivity by about 5 dB to -55 dBz in 5 km for 10 s averaging time.

The budget calibration is applied to determine the radar constant C in eq. 1. According to [1] C can be written as:

$$C = \frac{2^{10}\ln(2)\,\lambda^2\, l_{atm}\, l_{MF}\, l_{Sys}\, k_B T_0 B F_N}{\pi^3\, G^2\theta^2\, c\,\tau\, |K_w|^2 P_t} \tag{2}$$

The gain and loss of each radar component is determined during manufacture. The Table 1 lists all parameters of

Table 1. System parameters used in the radar equation and their estimated uncertainties for MIRA36.

	parameter	value	error	ΔZ_e
Transmitting power	P_t	20 .. 30 kW	3.5 kW	0.4 dB
Matched filter loss	l_{MF}	1.8 dB	0.3 dB	0.3 dB
Receiver Noise Figure	F_N	6.0 dB	0.5 dB	0.5 dB
Loss by wave guides	l_{sys}	2*0.65*length [dB]	0.2 dB	0.2 dB
Antenna aperature	$G^2 * \Theta^2$	1.5 dBi	1.5 dB	1.5 dB
Constant	K_w^2	0.93	± 0.2	0.09 dB

eq. 2, their estimated maximum errors and their influence on Z. The transmitting power and the receiver noise are continuously monitored by a thermistor and a noise diode, respectively. Furthermore, λ is the wavelength, τ the pulse length, k_B the Stefan Boltzmann constant, c the speed of light, T_0 the system temperature, B the receiver bandwidth ($= 1/\tau$) and l_{atm} the attenuation in the atmosphere.

The antenna parameters account to the radar constant by the factor $G^2 * \Theta^2 \approx 160 * G$, because the gain is related to the beam width by $G = 160/\Theta^2$

The maximum error of Z is the sum of each individual error component and amounts to about 3.0 dBz. That is the worst case when all errors have the same direction. In reality it should be much smaller. But, nevertheless an independent check would be very valuable.

3. MOMENT STATISTICS

For the statistics a data base which contains instantaneous values for each 10 min and 100 m in height has been created for the complete period of operation (2004-2011). Only moments with significant signals (greater than the noise level) were considered for the calculation of mean values. Figure 1 shows the histograms of all three moments and the LDR for the period 2010/2011. It gives some insight about the performance of the system and the vertical distribution of targets and their properties. For Z the left edge of the histogram is given by the minimum detectable signal which increases with height by $1/r^2$. Below 1 km the frequency maximum of reflectivity occurs between -30 and -40 dBz. It can be explained by non-hydrometeors (insects) which are typical for the boundary layer in the warm season. At upper heights the maximum decreases from -20 dBz at 5 km down to about -40 dBz at 10 km. The histogram of Doppler velocity is characterized by a maximum of -0.5 m/s at 10 km decreasing to -1.0 m/s at 3 km. This can be explained by growing ice particles when falling down. Below 3 km the downward motion of precipitation with values of up to -8 m/s are clearly visible. Insects yield a frequency maximum of about -0.2 m/s below 1 km. The spectral width covers a range from about 0 up to 2 m/s below 3 km, while above this height the spectral width is smaller than 0.8 m/s. The LDR has two distinct maxima in the boundary layer, one at about -12 dB caused by insects and another one at about -28 dBz.

The time series of reflectivity (monthly means) in Fig. 2 for four different height levels illustrate the annual cycle and long term changes. A annual cycle is most evident at the highest level (10 km). At this height cirrus is the dominating cloud type. It was been found for midlatitudes that in the warmer season cirrus is more frequent, thicker and has a larger ice water content and effective radius [8] than in winter. This would explain the higher reflectivity in summer. At 1000 m and 500 m no clear annual cycle can be recognized. To estimate the long term trend a linear regression line has been calculated for the complete period and for the period until January 2010, after which the system was upgraded. The lowest level shows a negative trend, whereas the trend at the levels above is positive. The total change within the 8 years (60 months) varies between -0.9 and 2.6 dBz. Unfortunately, it is not possible to distinguish between natural variations and system drifts. Looking to the year to year variations for each month (Fig. 3), a similar behavior between the different months can be seen. That is an indication for variations in the calibration constant because it is unlikely that each month show the same natural variation.

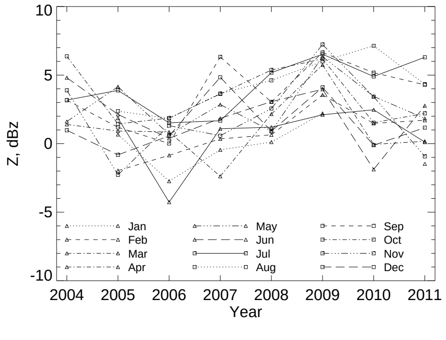

Figure 3. Time series of mean reflectivity separated for each month

4. FURTHER ERROR SOURCES

Besides the calibration issue some other error sources can influence the measurement results and should be kept

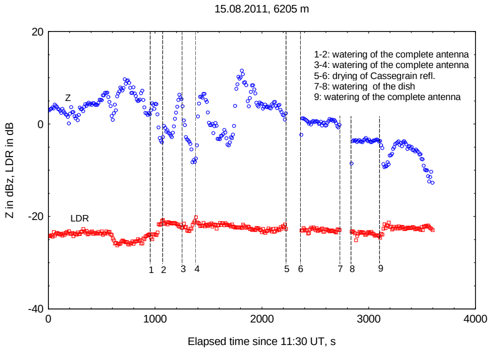

Figure 4. Time series of reflectivity and LDR at one height level for a dry and wet antenna

in mind when interpreting cloud radar measurements. There are doubts if incoherent scattering is the only scattering process as there might be contributions from coherent scattering as described in [2, 9]. Furthermore, the attenuation in the atmosphere by gas and/or particles can amount to several dBz per kilometer [7]. The radar signal is also attenuated by water on the antenna. Errors can also be caused by the signal processing or non-optimum parameter settings. Last but not least there may be backscatter from unknown targets.

Here, two examples will be shown to demonstrate the effect of a wet antenna and showing that certain backscatter signals can not be explained by hydrometeors.

In order to get a first idea about the effect of a wet antenna a simple experiment has been carried out. On a day with a stratiform middle level cloud a hosepipe was used to spray the antenna with water in different intensities. Time series of reflectivity and LDR are plotted in Fig. 4. It can be seen that a wetting of both the antenna dish and the small Cassegrain reflector on the top (mark 1, 3 and 9 in the figure) yields a decrease of Z by about 5 to 15 dBz. At the same time the LDR is increased by about 5 dB. If only the dish is watered (which may occur in situations with light rain and wind, mark 7) a smaller reduction by about 2 to 5 dB occurred. That means, that droplets on the Cassegrain reflector and the plastic cap, respectively, have obviously a notable impact on reflectivity measurements.

Fig. 5 shows the LDR of cloud similar targets. The origin of this cloud can not be explained. The other moments show no distinctive characteristic compared to normal clouds. Such clouds are observed irregularly about 10 times a year. The first presumption that chaff has caused this signal could not be verified so far.

5. CONCLUSION

It has been found that the budget calibration of MIRA36 can have a systematic error of up to 3.0 dBz in the most unfavorable case. During precipitation an additional error of several dBz can be caused by a wet antenna. Therefore, an independent radar calibration should be pursued. While moment statistics can not quantify the magnitude of error, they give at least an evidence about long term stability of calibration.

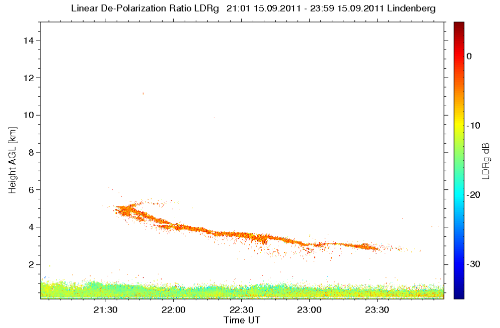

Figure 5. LDR for a cloud with unknown origin

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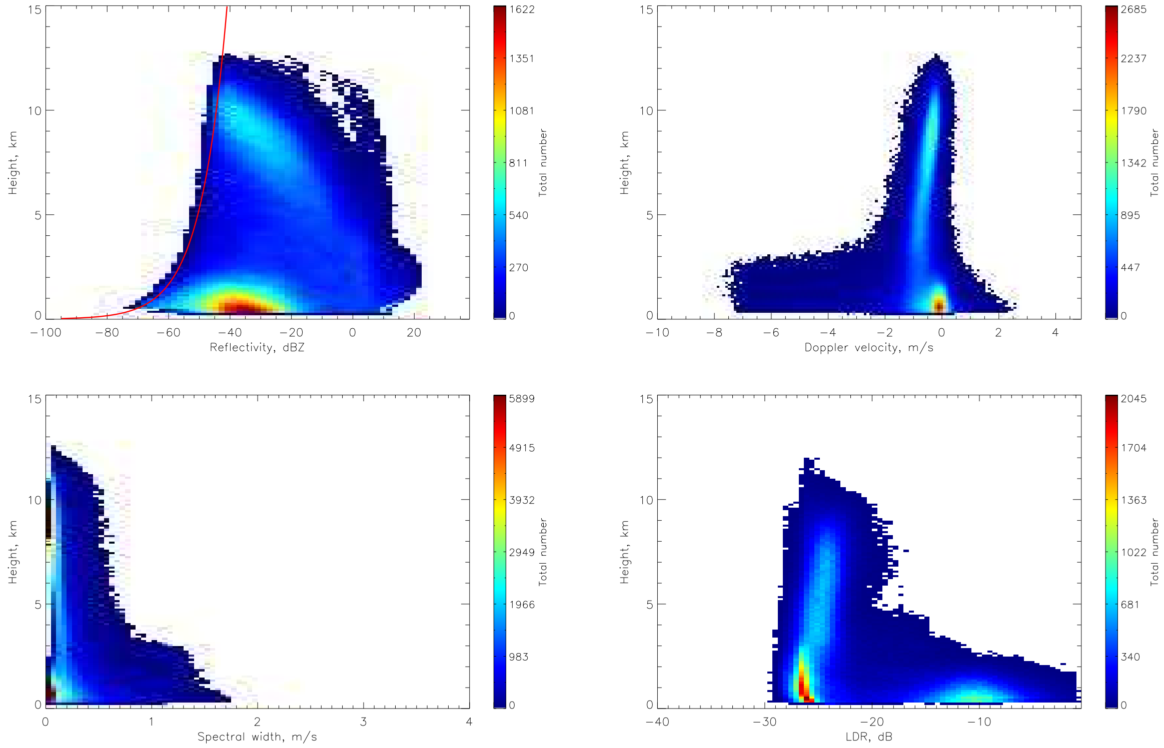

Figure 1. Histogram of moments for 2010/2011

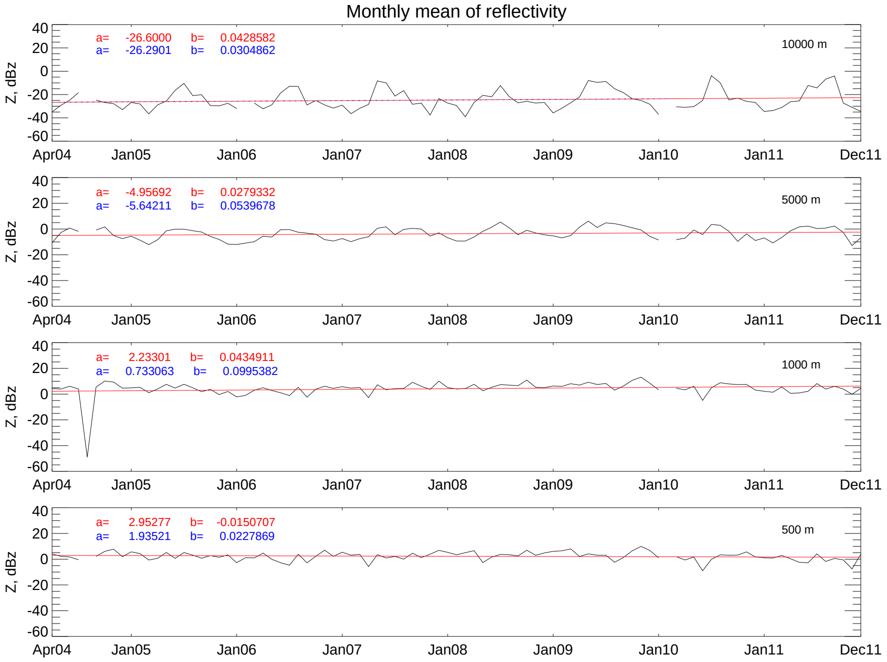

Figure 2. Mean monthly reflectivity for four height levels. Red is the linear regression line and the corresponding parameters for the equation y = a + bx, blue is the same but only until January 2010.